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PREFACE

This project memorandum is the result of research and development sponsored by the United States Air Force (USAF) Global Air Traffic Systems Group of the Electronic Systems Center at Hanscom Air Force Base, MA. The authors have prepared this report to assist the USAF in the task of equipping their aircraft with appropriate Mode S avionics to support the European mandate for "Elementary Surveillance" (ELS) and "Enhanced Surveillance" (EHS) applications.

The authors acknowledge the many writers and reviewers who prepared references [1] through [6], from which this project memorandum derives much of its material. The authors would like to thank the reviewers who provided many significant comments and corrections on earlier drafts of this project memorandum, with special thanks to Bob Saffell, Dieter Kunze, Vince Orlando, Ann Drumm, Val Heinz, and Garrett Harris. Finally, the authors acknowledge the input from the "European Organisation for Civil Aviation Equipment" (EUROCAE) "Mode S Enhanced Surveillance" Working Group 49 who provided valuable comments on an early draft of this text.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

EXECUTIVE SUMMARY

This project memorandum discusses the three main applications of the Mode S-Specific Protocols (MSP) that are currently being fitted to aircraft and ground systems worldwide and are being considered for future military and civilian functions. It also seeks to provide a common and organized summary of the requirements and specifications for the Mode S avionics employed in these applications. The three MSP applications described in this project memorandum are:

ELS	Elementary Surveillance;
EHS	Enhanced Surveillance; and
ADS-B	Automatic Dependent Surveillance via Broadcast, also called 1090 MHz "Extended Squitter" (ES).

Elementary Surveillance

ELS support is required by the European Mode S equipage mandate. Support of ELS consists primarily of populating and maintaining four Mode S transponder registers:

10_{16}	Data Link Capability Report;
17_{16}	Common-Usage Ground-Initiated Comm B (GICB) Capability Report;
20_{16}	Aircraft Identification Register; and
30_{16}	Airborne Collision Avoidance System (ACAS) Resolution Advisory (RA).

The first two of these registers form the basis for the transponder configuration, register extraction, and fault-detection protocols used by all MSP applications. There are several other registers used to configure a Mode S transponder for varying levels of data link applications, but the two basic transponder registers (10_{16} and 17_{16}) are sufficient for the application set described in this project memorandum. The later two of the ELS-required transponder registers provide the aircraft flight identification and information about the state of the onboard ACAS equipment. The definition, specification, and content of the ELS application data is well defined and quite mature.

It should be noted that the European ELS mandate also includes the requirement to support the Mode S "supplemental interrogator identifier" (SI) code protocol. The SI protocol allows for more-complex overlapping coverage by multiple Mode S ground sensors. This is seen as an immediate need in European airspace.

Enhanced Surveillance

EHS support is required by the European Mode S mandate. Support of EHS consists of populating and maintaining three Mode S transponder registers beyond those required for ELS:

40_{16} Selected Vertical Intention;

50_{16} Turn and Track Report; and

60_{16} Heading and Speed Report.

These Mode S registers are intended to support improved ATC systems where knowledge of the aircraft's intended flight path can be used to supplement surveillance tracking. The data fields in these registers are simply a reformatting of values expected to already exist in the aircraft on its ARINC 429 data buses. The register definitions provide a status bit for each data field. A particular avionics suite may provide a subset of the data available from its onboard flight management system or other avionics. Register 40_{16} is the most complex of the EHS register set, since it uses a wide variety of data sources. Different aircraft configurations (e.g., Boeing versus Airbus) may need to set the data fields in this register differently.

It should be noted that the definition of the contents of register 40_{16} has been redefined from an earlier version that sought to provide 3-dimensional intent information in a single register. The current register 40_{16} definition has been limited to vertical intent only as this is the data with the most immediate ATC application.

Automatic Dependent Surveillance via Broadcast

The specification of the Mode S ADS-B (1090 MHz Extended Squitter) application is by far the most complex of the MSP applications described in this project memorandum; its description occupies nearly half the pages. One reason for this complexity is simply the number of registers defined for this application. There are six "basic" 1090 MHz ES ADS-B registers (five more "event-driven" ADS-B registers will be discussed later):

05_{16} Airborne Position;

06_{16} Surface Position/Velocity;

07_{16} Application Status;

08_{16} Aircraft Identification;

09_{16} Airborne Velocity; and

$0A_{16}$ Event-Driven Information.

Note that 1090 MHz ES ADS-B separates position from velocity data in the airborne case. This is done because there are not enough bits in a given Mode S transponder register to fully encode both position and velocity in three dimensions. A separate register is defined for the surface that incorporates both position and velocity fields. The ADS-B "aircraft identification" register (08_{16}) parallels the aircraft identification register (20_{16}) defined for the ELS application. The rationale for this apparent duplication of data is that ELS registers are extracted through an interrogation by an external Mode S interrogator, while ADS-B registers are spontaneously broadcast (squittered). No interrogation is required to receive the ADS-B data.

A second reason for the complexity of the Mode S ADS-B definition is that two different versions of the specification are currently being maintained. The original specification (termed "version 0") is given in Radio Technical Commission for Aeronautics (RTCA) DO-260 published in 2000. A newer specification (termed "version 1") is given in RTCA DO-260A published in 2003. Version 1 is largely backward compatible with version 0, especially for the six "basic" ADS-B registers. Version 1 differs from version 0 in two areas: (a) its specification of the ADS-B "event-driven" transponder register set; and (b) how available avionics surveillance accuracy is specified.

The five Mode S 1090 MHz ES ADS-B "event-driven" transponder registers extend the basic set of broadcast data to include slowly changing values or rare events that need not be continuously broadcast. As was the case for aircraft identification, this broadcast mechanism parallels the operation of other Mode S transponder registers whose contents are obtained by interrogation/extraction. The 1090 MHz ES ADS-B "event-driven" register set is:

- 61_{16} Emergency/ACAS RA;
- 62_{16} Current Trajectory Change Point;
- 63_{16} Next Trajectory Change Point;
- 64_{16} Aircraft Operational Coordination Message; and
- 65_{16} Aircraft Operational Status Message.

The ACAS RA data in register 61_{16} parallels that in ELS register 30_{16}, and the aircraft's emergency state may also be obtained via direct Mode S surveillance. The data in registers 62_{16} and 63_{16} were defined to provide long-term aircraft intent information for potential conflict detection and resolution algorithms to be supported via 1090 ES. Again, this data is equivalent to that defined in other registers whose contents may be obtained via direct Mode S interrogation/extraction. Support for registers 62_{16} and 63_{16} was removed from the version 1 definition of 1090 MHz ES ADS-B. Register 64_{16} was envisaged to support various "paired" aircraft applications (formation flying). It is also no longer supported in version 1. The definition of register 65_{16} has been greatly expanded in version 1 to support various potential airborne and surface operations.

As was indicated above, there are a number of registers and data fields defined for the 1090 MHz ES ADS-B application that parallel data available elsewhere in the Mode S transponder. The 1090 ES ADS-B broadcast (squitter) protocol is seen by its designers to operate independently from applications employing Mode S interrogation/extraction (e.g., ELS and EHS). Also, it is seen that the set of 1090 ES ADS-B supported applications is quite fluid and undergoing change. The requirements for support of ADS-B applications beyond the "basic" set are not yet firm.

Also, the version 0 and version 1 definitions of 1090 MHz ES ADS-B differ in how the available avionics surveillance accuracy is specified. Version 0 avionics use a "navigation uncertainty category" (NUC), while version 1 avionics provide a "navigation accuracy category" (NAC), a "navigational integrity category" (NIC), and a "surveillance integrity level" (SIL). There are no current operational uses for these values, nor is there a determination of how all this information would be used by 1090 MHz ES ADS-B applications.

ELS/EHS/ADS-B Summary

In summary, the Mode S ELS and EHS applications as required by the European mandate are mature and stable. Equipping for these Mode S applications is relatively straightforward. The source of data for the ELS and EHS registers is largely the aircraft's ARINC-429 buses. The task of populating the required Mode S registers is primarily a reformatting process.

The case of the Mode S 1090 MHz ES ADS-B application is somewhat different from the ELS and EHS applications. The 1090 MHz ES ADS-B application is more complex than ELS and EHS. This additional complexity arises from several areas:

- The 1090 MHz ADS-B application requires more Mode S transponder register definitions than ELS and EHS;
- There are two application specification versions for 1090 MHz ES ADS-B; and
- The data formatting and control protocols required for 1090 MHz ES ADS-B are more complex than those used in ELS and EHS.

There is no current equipage mandate for 1090 MHz ES ADS-B systems. There is a prototype ADS-B implementation in Alaska (project Capstone). An operational ADS-B surveillance system using 1090 MHz ES exclusively is currently being installed in Australia. Some air-to-air usage of 1090 MHz ES messages to augment TCAS is also underway. The operational concepts for ADS-B applications are less stable than those for ELS and EHS, and these operational concepts are likely to evolve as they mature. Some currently defined features of the 1090 MHz ES ADS-B application may never be implemented.

1 Introduction

This Project Memorandum presents guidance material for the use of the "Ground-Initiated Comm. B" (GICB) transponder register set within a Mode S avionics installation. The intent of this Project Memorandum is to reduce the effect of complexity in various implementations of Mode S transponder applications resulting from the number of documentation sources and revisions that have occurred over time. This Project Memorandum combines information from several sources, including references [1] through [6]) into a single and organized entity. It focuses on the "Elementary Surveillance" (ELS), "Enhanced Surveillance" (EHS), and "Automatic Dependent Surveillance via Broadcast" (ADS-B, also called 1090 MHz Extended Squitter) applications, as well as support of military surveillance functions. The information in this Project Memorandum will also help in the development of other Mode S data link applications.

Section 2 of this Project Memorandum discusses the configuration settings in the aircraft Mode S transponder and avionics required to support Mode S data link applications such as ELS, EHS, and ADS-B. Section 3 goes on to describe the protocols employed by Mode S data link applications to determine the avionics configuration and to deal with changes in configuration due to equipment failures. Section 4 describes the additional Mode S transponder register support required for the ELS application. Section 5 describes the additional registers required for the EHS application. Section 6 describes the additional registers and associated protocols required for the Mode S 1090 MHz Extended Squitter (ADS-B) application. Finally, section 7 describes the additional registers used to support military surveillance identity codes.

Although the information provided in this Project Memorandum is drawn from several approved national and international standards, it is not intended to replace or supersede those standards. Rather, this report is meant to provide guidance for system implementers. In the event of a conflict or contradiction between this document and any approved standards, the approved standards take precedence and the reader is encouraged to contact the author of this report.

Note: This document contains many references to Mode S transponder registers. Following international documentation standards, they are listed as hexadecimal numbers. In this document, register numbers are stated as hexadecimal values (subscript "$_{16}$"). Also, there are many references to ARINC 429 labels, which are expressed herein in octal (subscript "$_{8}$").

The following figure illustrates the organization and basic data flows for the subset of the registers used in the ELS, EHS, ADS-B, and military applications.

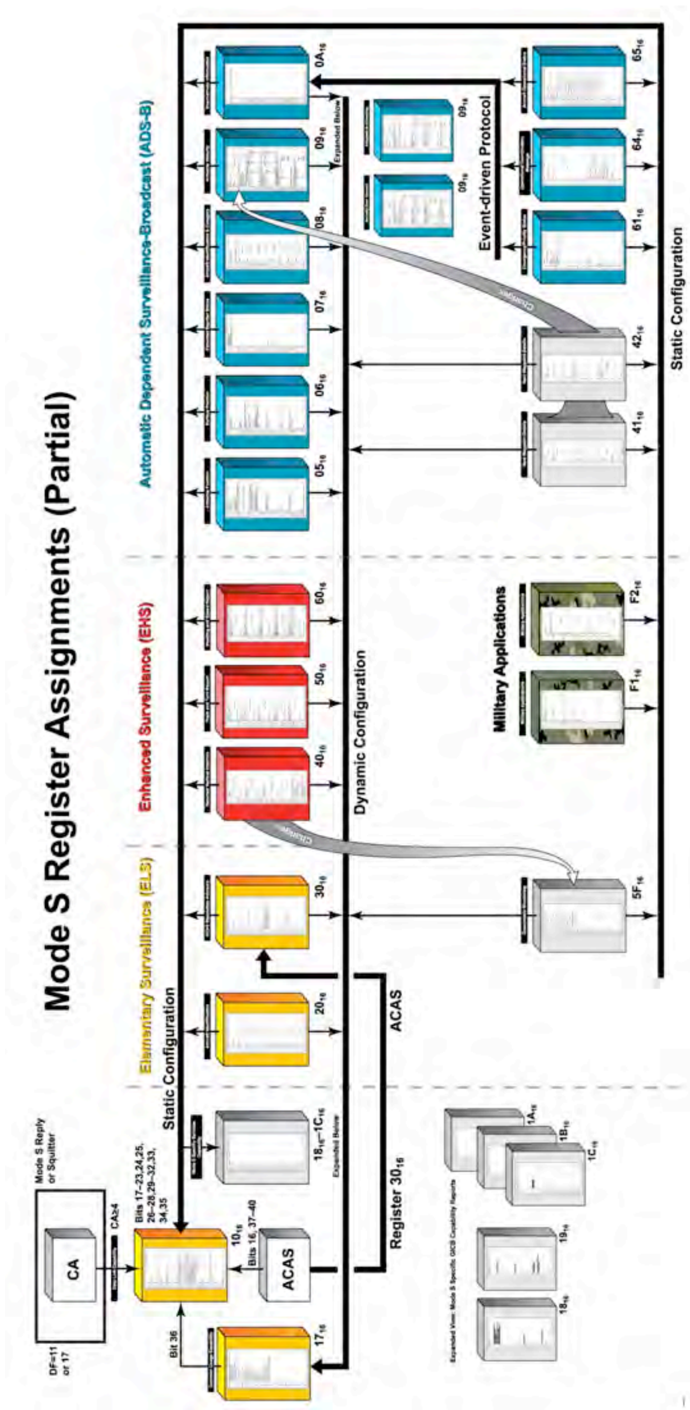

Figure 1-1: Mode S Register Assignments for ELS, EHS, and ADS-B

This figure illustrates the organization and basic data flows for the subset of the registers used in the ELS, EHS, ADS-B, and military applications. Color-coding is used to group the registers by application: ELS (yellow), EHS (red), ADS-B (blue), and military (green). Registers shown in gray are indirectly involved with these applications, but are not directly called out by the application specification. The figure employs thick arrows to denote the transponder static and dynamic configuration data flows and the ADS-B event-driven protocol.

2 Avionics Configuration Settings

This section describes the various registers used to specify the configuration of the Mode S avionics with respect to the various Mode S applications (e.g., ELS, EHS, and ADS-B) that might be installed on the aircraft. Two sets of these registers (the Mode S-Specific services GICB capability reports and the "Mode S-Specific Protocol" [MSP] capability reports) are static and simply indicate the airborne configuration. Two other configuration registers (the common usage GICB capability report and the data link capability report) combine static configuration information with dynamic status information on the timeliness of data within certain other registers. Combined with the "configuration and failure protocols" described in section 3 below, these registers allow the sensor extracting data from the transponder to ascertain which data values are valid in the transponder's registers.

2.1 Mode S-Specific Services GICB Capability Reports (Registers 18_{16}..$1C_{16}$)

Registers 18_{16} though $1C_{16}$ are used to specify which of the 255 possible registers are actually implemented in the particular avionics configuration. (There is no register zero.) Note that these capability bits indicate only that the avionics are configured to be able to load the indicated register – these bits do not indicate whether the register is, in fact, being loaded in a timely manner. The indication of timely data is performed for "important" register applications via the "common usage capability report" register 17_{16} (see section 2.3 below). If there is no bit assigned in register 17_{16} for the particular register of interest, then a status bit (or bits) within the particular register itself must to be tested to determine if the register is being loaded appropriately.

The installed capability for registers is indicated by setting the appropriate bit corresponding to the given register in the GICB Capability Report register as indicated in the following table. The bit position numbering for each register capability bit starts with the least significant bit (LSB, bit 56) of each register. The 25 most-significant bits in register $1C_{16}$ are not used.

Table 2-1: Register Configuration Bit Assignments in Mode S-Specific Services GICB Capability Reports

First GICB	Last GICB	Capability Register
01_{16}	38_{16}	18_{16}
39_{16}	70_{16}	19_{16}
71_{16}	$A8_{16}$	$1A_{16}$
$A9_{16}$	$E0_{16}$	$1B_{16}$
$E1_{16}$	FF_{16}	$1C_{16}$

2.2 Mode S-Specific Services MSP Capability Reports (Registers $1D_{16}$..$1F_{16}$)

Registers $1D_{16}$ through $1F_{16}$ contain bits that indicate which (if any) of the 63 uplink and the 63 downlink MSP channels are supported by the particular avionics installation. (Note: these functions are not required for the support of ELS, EHS, or ADS-B 1090 Squitter. Example MSP functions include the “Traffic Information Service” [TIS. uplink channel 2] and ACAS sensitivity control [uplink channel 5].) The bits in the Mode S-Specific services MSP capability report registers simply indicate the configuration, not whether the MSP functions are currently operational.

Within each of the Mode S-Specific services MSP capability reports, the high-order 28 bits of each register are used to specify the configuration state of uplink MSP channels, while the low-order 28 bits of each register are used to indicate the configuration state of the corresponding downlink MSP channels. Register $1D_{16}$ indicates the configuration status of MSP channels 1 through 28 (uplink and downlink). Register $1E_{16}$ indicates the configuration status of MSP channels 29 through 56. Register $1F_{16}$ indicates the configuration status of MSP channels 57 through 63. The remaining bits in register $1F_{16}$ are unused.

2.3 Common Usage GICB Capability Report (Register 17_{16})

Register 17_{16} contains a series of bit flags that indicate the status of a subset of the Mode S transponder’s registers deemed to be of “common usage”. All of the registers involved with the ELS, EHS, and ADS-B applications of Mode S have bit flags assigned in this register. These bit flags partly parallel the similar bit flags in the Mode S-Specific Services GICB Capability Reports – they cannot be set unless the avionics configuration supports the particular register. Providing a single capability register for all the “commonly used” registers allows a sensor to obtain all the configuration information it needs for a given aircraft with a single GICB register extraction – instead of having to pick bits from multiple registers in the range 18_{16} through $1C_{16}$ for each register that is of interest to the sensor.

Unlike the bit flags in the Mode S-Specific Services GICB Capability Report registers, the bit flags in the “common usage” GICB capability report are not a static indication of whether the particular register is installed in the aircraft’s avionics. Rather, the bit flags in register 17_{16} are dynamic – if set, they indicate that the particular register has been updated in a timely manner and contains valid data. All registers having bit flags in register 17_{16} are continually monitored at a rate consistent with the update rate required for the individual register. The bit flag is set to ‘1’ by the transponder only if valid data is being input to that register at the required rate.

The bit flag in register 17_{16} for a given register is set to '1' if at least one data field in that register is receiving valid data at the required rate. The data field status bits in the given register itself indicate which of the data items in the register are current and valid. Each of the EHS registers contain several data items, therefore to ensure compliance with the European mandates it is important to verify that each field status bit is set, and then verify that the bits in each of the data fields are set to some non-zero value. For completeness, a final check should compare the values in those data fields with an independent surveillance source, such as radar, to verify that the values are correctly reporting the aircraft's state.

There is a bit in the “data link capability report” (see section 2.4 below) combined with an avionics protocol (see section 3.0 below) that is used to signal changes in the contents of register 17_{16} (indicating loss of timely data in one or more registers being supported in the avionics). The sensor will, in absence of avionics failures, only have to extract the contents of register 17_{16} once.

2.4 Data Link Capability Report (Register 10_{16})

The Data Link Capability Report (register 10_{16}) is the root source of configuration and operational status information for the Mode S avionics system. Register 10_{16} contains subfields that describe the capabilities and operational status of the Mode S transponder itself, its support for Mode S data link applications (e.g., ACAS, ADS-B, etc.) and its support for the Mode S subnetwork of the Aeronautical Telecommunications Network (ATN). This section discusses primarily those subfields of the Data Link Capability Report register that are pertinent to the ELS, EHS, and ADS-B applications. See [3] for a complete definition of this register.

The first eight bits of register 10_{16} contain the fixed value 10_{16} – used to identify the Data Link Capability Report when it is broadcast via the air-initiated Comm-B protocol. A Mode S transponder broadcasts the contents of register 10_{16} whenever its contents change (indicating some sort of change and/or failure mode in the Mode S avionics). Bit 24 of register 10_{16} is used to indicate whether the Mode S transponder can support the "enhanced protocol" of Mode S – the ability to perform extended length message (ELM) transactions with more than one sensor simultaneously. Bit 35 of register 10_{16} is used to indicate whether the Mode S transponder can support the "surveillance identifier" (SI) code extension to the Mode S link protocols. Bits 26 through 28 of register 10_{16} are used to indicate the rate at which the Mode S transponder can perform uplink ELM transactions. Bits 29 through 32 of register 10_{16} are used to indicate the rate at which the Mode S transponder can perform downlink ELM transactions. All of these static configuration settings are functions of the Mode S transponder capabilities. (Note: the ELS, EHS, and ADS-B Mode S data link applications of Mode S do not employ ELM transactions [either uplink or downlink] or the "enhanced protocol".)

Bit 25 of register 10_{16} is used to indicate whether the Mode S avionics are configured with any Mode S-Specific service applications. These applications include extraction of any registers excepting 02_{16} through 04_{16}, 10_{16}, 20_{16}, and 30_{16}. They also include any MSP applications as discussed in section 2.2 above. This is a static bit indicating the avionics configuration.

Bit 33 of register 10_{16} is used to indicate whether the Mode S avionics are configured to support the extraction of aircraft identification (register 20_{16}). If this bit is set statically, it mirrors bit 25 of register 18_{16}. However, it is preferable to set this bit dynamically to mirror bit 7 of register 17_{16} (which indicates that the aircraft identification is currently valid). Bit 34 of register 10_{16} is used to indicate whether the Mode S avionics are configured to support ADS-B applications. Bit 34 is set if both the airborne and surface position registers (05_{16} and 06_{16}) have been updated within the last ten seconds. Hence, the setting of bit 34 is dynamic and equivalent to the "and" of bits 1 and 2 of register 17_{16} (bits 1 and 2 indicate the configuration of registers 05_{16} and 06_{16} respectively).

Bit 36 of register 10_{16} is used to indicate whether the contents of the common usage capability register 17_{16} (see section 2.3 above) have changed. Such a change indicates some sort of failure mode in the Mode S avionics. Bit 36 is toggled each time the content of register 17_{16} changes. By changing the value of bit 36 in register 10_{16}, a downlink of the data link capability report (via the air-initiated Comm B broadcast protocol) is generated – sensors do not need to poll the register contents to detect failures in the Mode S avionics. To avoid generation of too many broadcasts of the data link capability report, register 17_{16} is sampled at a 1-minute rate to detect changes. A further discussion of the protocols for extracting and monitoring the configuration and failure status of an aircraft's Mode S avionics is given in section 3.0 below.

Bits 16 and 37 through 40 of register 10_{16} are used as bit flags to indicate the status of an ACAS application that might be installed as part of the aircraft's Mode S avionics. The following table defines the use of these ACAS bit flags.

Table 2-2: ACAS Configuration Bits in Data Link Capability Register (10_{16})

Bit	Usage
16	0 ➔ ACAS failed or in standby 1 ➔ ACAS operational
37	0 ➔ ACAS II 1 ➔ ACAS III (reserved)
38	0 ➔ ACAS generating TAs only 1 ➔ ACAS generating TAs and RAs
39	0 ➔ no ACAS onboard 1 ➔ ACAS onboard
40	Reserved for ACAS

Bits 17 through 23 of register 10_{16} are used to denote the documentation version of International Civil Aviation Organization (ICAO) standards [3] and [4] used to encode the register contents in the aircraft's Mode S avionics. The register definitions must be consistent with one document version, although only a subset of the documents' features need be installed. The version number should be set if any Mode S-Specific services are used in the avionics (i.e., if bit 25 of register 10_{16} is set). The following table defines the coding of the version number field.

Table 2-3: Version Number Coding in the Mode S Data Link Capability Register (10_{16})

Coding	Year of Annex 10 amendment [3]	Edition of ICAO Manual [4]
0	Mode S subnetwork not available	
1	1996	Not applicable
2	1998	Not applicable
3	2002	Not applicable
4	2007 (planned release)	Edition 1
5..127	Unassigned	

2.5 Transponder and ACAS Type / Part Number / Software Revision (Registers $E3_{16}$, $E4_{16}$, $E5_{16}$, $E6_{16}$)

The recent issue of the Mode S GICB register formats [6] includes a set of four registers that are used to specify the type and software revision of the Mode S transponder and ACAS unit (if any) on board the aircraft. Registers $E3_{16}$ and $E4_{16}$ refer to the transponder itself, while registers $E5_{16}$ and $E6_{16}$ refer to the ACAS unit. The first register of each pair refers to the part number or type specification of the equipment, while the second register of each pair refers to the software revision hosted in the equipment. (Note: for operational reasons, some military installations may not populate these registers.)

The format of all four registers is the same. The first bit in the register format is a status flag that indicates the validity of the data in the register. The next two bits in the register form a format type code value. The format type code value '0' indicates that the remainder of the register uses the "part number" (P/N) format – a decimal digit string. The format type code value '1' indicates that the remainder of the register uses the Mode S character format. Type codes '2' and '3' are reserved.

If the format of the register is P/N, then the part number is expressed as a string of up to 12 "binary-coded decimal" (BCD) digits. This is the recommended format for the expression of these registers. If the part number (revision number) is not available, then the first 8 characters of the commercial name are encoded in the register using the Mode S character string format. As described in section 4.1 below (and in [1]), the Mode S character format uses 6 bits for each character. Letters 'A' through 'Z' are encoded using values 1 through 26. Digits '0' through '9' are encoded using values 48 through 57. The space character is encoded as value 32. All other encoding values are undefined. For either P/N or character format, the last 5 bits of the register format are reserved.

3 Configuration and Failure Protocols

The first processing step for any Mode S data link application is to obtain the transponder capability (CA) value from the aircraft. The 3-bit CA field is found in the "Mode S All-Call Reply and Acquisition Squitter" (DF=11) and the "Extended Squitter" (DF=17) downlinks. If CA=0, then this transponder is surveillance-only and supports no data link functions at all. If CA=1, 2, or 3, then this transponder is using an earlier form of the Mode S protocol. These Mode S transponders support only GICB extraction of the aircraft's data link capability (register 10_{16}), aircraft identity (register 20_{16}), ACAS RA (register 30_{16}), and air-initiated Comm B broadcast. Values of CA greater than or equal to 4 indicate that the Mode S transponder is fully capable of at least short uplink and downlink message transfer. These Mode S transponders can support the ELS, EHS, ADS-B, and other data link functions (given that their avionics load the appropriate registers, etc.). The Mode S transponder CA value should be stored in the data link application as part of the aircraft "state". (See [1] for a full description of the transponder capability values.)

Given that the Mode S transponder's CA value is 4 or greater, the second processing step for any Mode S data link application is to extract the transponder's Mode S capability report (register 10_{16}) as described in section 2.4 above. The contents of this register should be stored in the data link application as part of the aircraft "state". Bits in this register indicate the support of such Mode S data link functions as aircraft identification, ADS-B, ACAS, etc. The Mode S-Specific services capability bit indicates whether the avionics installation supports further data link functions. If this bit is set, the Mode S data link application would next extract the common-usage capability register (17_{16}) as described in section 2.3 above. The contents of this register would also be stored as part of the aircraft "state".

The processing protocol described in this section so far is sufficient initialization for basic data link applications such as ELS, EHS, and ADS-B, since all their status and configuration information is available from registers 10_{16} and 17_{16}. Other Mode S data link applications (e.g., Traffic Information Service [TIS]) might need to extract one or more of the Mode S-Specific services GICB capability reports (see section 2.1 above) or one or more of the Mode S-Specific services MSP capability reports (see section 2.2 above) to determine whether the aircraft's avionics support the particular Mode S data link application. The additional capability register contents also become part of the aircraft "state" in the application.

This completes the initialization processing for Mode S data link applications. The application should subsequently monitor any air-initiated Comm B broadcast messages received from the particular aircraft in order to detect any changes in the aircraft's configuration status. Any changes in the contents of any of the registers 10_{16}, 20_{16}, or 30_{16} triggers a downlink message via the air-initiated Comm B broadcast protocol including the updated register contents. The Mode S data link application should update the aircraft's "state" values with the new ones. The changed state might result in discontinuance (or reinstatement) of certain Mode S data link functions. A change in the value of the common-usage GICB report bit in the data link capability report (register 10_{16}) would cause the application to re-extract the contents of the common-usage GICB capability report (register 17_{16}). (Note: Mode S transponder air-initiated Comm B broadcast messages are held active in the transponder for 18 seconds after the triggering event. Any Mode S sensor can extract the broadcast information.)

If the Mode S data link application cannot receive air-initiated Comm B broadcast messages, it would need to periodically poll the Data Link Capability Report (GICB register 10_{16}) to detect changes. The polling period would be somewhere between 12 and 60 seconds. If the Mode S data link application seeks to detect ACAS RA information, it would also need to periodically poll the ACAS RA report (register 30_{16}).

Other Mode S data link applications beyond ELS, EHS, and ADS-B (e.g., TIS, ACAS sensitivity control, etc.) implement their own protocols for indicating status changes (transponder air-initiated Comm B broadcast messages, register bits to poll, etc.). These protocols are specific to the particular Mode S data link application. However, they typically involve similar processes.

4 Elementary Surveillance (ELS) Transponder Registers

The "Elementary Surveillance" application (ELS) includes registers 10_{16} and 17_{16} as discussed in sections 2 and 3 above. In addition, ELS includes the "aircraft identification" register (20_{16}) and the "ACAS resolution advisory" register (30_{16}). This section provides guidance on the contents and operation of registers 20_{16} and 30_{16}.

4.1 Aircraft Identification (Register 20_{16})

The intent of this register is to provide a means for applications to correlate surveillance data (containing the Mode S address and the Mode 3/A code) with the flight plan (containing the aircraft identification). The aircraft identification register contains an 8-character text string that is to be set equal to the flight plan identification (if one is available) – otherwise, it should be set to the aircraft's registration marking. The text string should be left justified in the register. No intervening "space" codes should be included in the text string. Any unused characters at the end of the text string should be set to the "space" code.

A 6-bit character encoding is employed that incorporates upper-case letters, decimal digits, and a space character. The encoding is described in [1]. Letters 'A' through 'Z' are encoded using values 1 through 26. Digits '0' through '9' are encoded using values 48 through 57. The space character is encoded as value 32. All other encoding values are undefined. The input text string could come from ARINC words $233\text{-}236_8$ (Flight Identification), $301\text{-}303_8$ (Aircraft Identification), or 360_8 (Flight Number).

Note that receiving applications will detect any changes in or loss of the contents of this register via an air-initiated Comm B broadcast message from the Mode S transponder. This broadcast downlink message occurs within 2 seconds of the change in or loss of the data in GICB register 20_{16}.

4.2 ACAS Resolution Advisory (Register 30_{16})

The format of the ACAS Resolution Advisory register content is defined in [3]. This register allows external systems (such as a ground Mode S sensor) to extract the current state of an ACAS system's resolution advisory display(s). The structure of the ACAS Resolution Advisory's 56 bits is illustrated in the following table.

Table 4-1: Field Definitions for the ACAS Resolution Advisory Transponder Register

Field Name	Number of bits
BDS	8
ARA	14
RAC	4
RAT	1
MTI	1
TTI	2
TID	26

The BDS field is set to 30_{16} to denote the ACAS resolution advisory when this data is broadcast. (An air-initiated Comm B broadcast downlink is generated whenever the register contents change.) The "Active RAs" (ARA) field indicates the characteristics of the RA (if any) generated by ACAS. The coding of the ARA field is described on the next page. The "RAs Active" (RAC) field is composed of four bit flags indicating the current state of active RA complements received by ACAS from other aircraft. The RAC field coding is shown in the following table.

Table 4-2: Bit Definitions within the RAC Field of ACAS Resolution Advisory Register

Bit in RAC field	Meaning if set
1	Do not pass below
2	Do not pass above
3	Do not turn left
4	Do not turn right

The "RA terminated" (RAT) bit is cleared (set to "0") if the ACAS RA in the ARA field is active. The RAT bit is set to "1" to indicate that the RA has been terminated. The "multiple threat indicator" (MTI) bit is set to "1" if two or more simultaneous threats are being processed by the ACAS. The MTI bit is cleared when there is a single threat or if there is no current threat, depending on the coding of the high-order bit of the ARA field. The "threat type indicator" (TTI) field defines the type of data in the "threat identity data" (TID) field that follows it. The coding of the TTI field is described in the table below.

Table 4-3: TTI Coding Definitions for the TTI Field of the ACAS Resolution Advisory Register

TTI Coding	Meaning
0	No identity data in TID
1	TID contains Mode S address
2	TID contains altitude, range, and bearing
3	Not assigned

If the TTI field value is ‘1’, the TID field contains the 24-bit Mode S address of the threat (when the threat is Mode S equipped). The low-order 2 bits of the TID field are cleared. If the TTI field value is ‘2’, the TID field is subdivided into three subfields as illustrated in the following table. Note: if there are multiple threats, the TID field contains data for the most-recently declared threat.

Table 4-4: TID Field Coding of the ACAS Resolution Advisory Register when TTI=2

TID Subfield	Number of bits	Coding
Altitude	13	Mode C altitude code of threat. Bit ordering is C1 A1 C2 A2 C4 A4 0 B1 D1 B2 D2 B4 D4
Range	7	0 ➔ no range estimate available 1 ➔ range < 0.05 Nmi. 2..126 ➔ (range – 1) / 10 Nmi. 127 ➔ range > 12.55 Nmi.
Bearing	6	0 ➔ no bearing estimate available 1..60 ➔ bearing in 6 degree increments 61..63 ➔ not assigned

The ARA field is a set of bit flags that can take on two sets of defined values, depending on the value of its high-order bit and the value of the separate MTI bit field. If the high-order bit of the ARA field is cleared, this indicates that there is more than one threat and the RA is intended to provide separation below some and above others (if MTI=1), or no RA has been generated (if MTI=0). If the high-order bit of the ARA field is set, this indicates that there is only one threat or the RA is intended to provide separation in the same direction for all the threats. The internal definitions for the remaining bit flags in the ARA field (when ARA bit 1=1) are illustrated in the following table.

Table 4-5: Internal Coding of ARA Field when ARA Bit 1=1

Bit number in ARA field	Definition (when ARA bit 1=1)
2	0 ➔ RA is preventive 1 ➔ RA is corrective
3	0 ➔ upward sense RA 1 ➔ downward sense RA
4	0 ➔ not increased rate 1 ➔ increased rate
5	0 ➔ RA is not a sense reversal 1 ➔ RA is a sense reversal
6	0 ➔ not altitude crossing 1 ➔ altitude crossing
7	0 ➔ RA is vertical speed limit 1 ➔RA is positive
8..14	Reserved for ACAS III

The internal definitions for the remaining bit flags in the ARA field (when ARA bit 1=0 and MTI=1) are illustrated in the following table.

Table 4-6: Internal Coding of ARA Field when ARA Bit 1=0 and MTI=1

Bit number in ARA field	Definition (when ARA bit 1=0 and MTI=1)
2	0 ➔ RA does not require upward correction 1 ➔ RA requires upward correction
3	0 ➔ RA does not require positive climb 1 ➔ RA requires positive climb
4	0 ➔ RA does not require downward correction 1 ➔ RA requires downward correction
5	0 ➔ RA does not require positive descent 1 ➔ RA requires positive descent
6	0 ➔ RA does not require altitude crossing 1 ➔ RA requires altitude crossing
7	0 ➔ RA is not a sense reversal 1 ➔RA is a sense reversal
8..14	Reserved for ACAS III

5 Enhanced Surveillance (EHS) Transponder Registers

This section discusses the three registers (40_{16}, 50_{16}, and 60_{16}) that make up the "Enhanced Surveillance" (EHS) function. (See [2] and [4] for the complete definition of these registers.) Whenever possible, the data value entered into the register should come from the sources in actual control of the aircraft. If the value of any data parameter received from the avionics data source exceeds the allowable range for the particular register format, the maximum allowable data value (with the appropriate sign) is encoded in the register. The least-significant bit for each encoded data value should be obtained via rounding. If any data value is not available in the aircraft's avionics, then all bits in the register value for that data should be cleared.

Within this section, the ARINC 429 word that provides the required data value is given in the accompanying tables. In some cases there is a choice of applicable ARINC 429 words for a data value – there may be a choice of ARINC 429 formats (binary or BCD), etc.

In addition to the EHS registers (40_{16}, 50_{16}, and 60_{16}), an additional register is used to provide Mode S applications a means to monitor changes in flight parameters that do not change frequently in normal flight (i.e., are expected to stay constant for 5 minutes or more at a time). An application can determine whether one or more of these flight parameters has changed by a single extraction of the "quasi-static parameter monitoring" register $5F_{16}$.

5.1 Selected Vertical Intention (Register 40_{16})

The selected vertical intention report (register 40_{16}) contains five data fields, each incorporating their own status bit. The maximum acceptable data age for any of the fields in this register is 1 second – if this age is exceeded for any data field then its corresponding status bit is cleared. The update rate for each data field in the register should be sufficient to ensure that the maximum latency of each data value is not exceeded in normal operation. (Note: if all five status fields in the register are simultaneously cleared, then the register itself is no longer valid. Its corresponding bit in the Mode S common usage capability register [17_{16}] should be cleared.)

The purpose of the data in register 40_{16} is to provide access to information about the pilot's intentions with respect to altitude changes during flight. This information could improve the effectiveness of conflict-probe applications and could provide an aid to air-traffic controllers in maintaining vertical separation among aircraft.

This register is the most complicated of the EHS register set (40_{16}, 50_{16}, and 60_{16}) with respect to the variety and complexity of data sources that must feed into the register's data fields. Different avionics configurations must deal with this register in different ways. See [2] and [4] for examples of the logic required to populate this register using typical Airbus and Boeing Mode S avionics installations.

The first data field in register 40_{16} is the selected altitude (also termed the "target altitude"). This is the short-term intent value at which the aircraft will resume level flight (or has already leveled off) at the completion of the current maneuver. The source of this data can be the aircraft's Mode Control Panel (MCP) or Flight Control Unit (FCU) (if the pilot is not flying the aircraft manually). The selected altitude field supports a "read-back" function so that ground surveillance applications can determine what the pilot has loaded into the aircraft's altitude control avionics. The second data field in this register is the selected altitude from the aircraft's Flight Management System (FMS). These data may be obtained from ARINC 429 label 102 (binary) or 025 (BCD).

The third data field in this register is the barometric pressure setting minus 800 millibars. This data value may be obtained from ARINC 429 label 234_8.

The fourth data field in this register is a set of three bit flags that indicate the Mode Status of the data source for the first data field. The first bit is set for VNAV mode (ARINC 429 label 272_8), the second bit is set for APPROACH mode (ARINC 429 label 273_8), and the third bit is set for ALT HOLD mode (ARINC 429 label 272_8). The status bit for this data field indicates whether mode information is being actively provided.

The fifth data field in this register holds the source of the altitude data being used to load this register. The following table describes the coding for the 2-bit altitude source value. Note: if the aircraft's avionics are not able to determine the source of altitude data (see [4] for the appropriate avionics logic), then the source field is to be cleared as well as its respective status bit.

Table 5-1: Coding for the Altitude Source Field in the Selected Vertical Intent (Reg. 40_{16})

Altitude Source Coding	Description
0	Unknown
1	Aircraft altitude
2	FCU/MCP selected altitude
3	FMS selected altitude

5.2 Turn and Track Report (Register 50_{16})

The Turn and Track Report (register 50_{16}) contains five data fields, each incorporating their own status bit. The purpose of this register is to aid conflict probe and long-term air traffic control functions in maintaining accurate aircraft horizontal track positions and velocities. The maximum acceptable data age for any of the fields in this register is 1 second – if this age is exceeded for any data field then its status bit in the register is cleared. The update rate for each data field in the register should be sufficient to ensure that the maximum latency of each data value is not exceeded in normal operation. (Note: if all five status fields in the register are simultaneously cleared, then the register itself is no longer valid. Its corresponding bit in the common usage capability register [register 17_{16}] should be cleared – which triggers a change in the data link capability register [register 10_{16}] and a downlink message is then sent via the air-initiated Comm B broadcast protocol.) The following table lists the data fields in register 50_{16}.

Table 5-2: Data Fields in the Turn and Track Report (Register 50_{16})

Data Field	LSB	Range	ARINC 429 word (octal)
Roll angle	45/256 degrees	-90..90 degrees	325
True Track angle	90/512 degrees	-180..180 degrees	313 (binary) 013 (BCD) 103 (GNSS[1] - binary)
Ground Speed	2 knots	0..2046 knots	312 (binary) 012 (BCD) 112 (GNSS – binary)
Track Angle Rate	1/32 degree/second	-16..16 degree/second	335 (see note below)
True Airspeed	2 knots	0..2046 knots	210 (binary) 230 (BCD)

Note: for ARINC General Aviation Manufacturers Association (GAMA) avionics configurations, ARINC 429 label 335_8 is not used for the true track angle rate but for another parameter. For this particular ARINC configuration the true track angle rate field in the Turn and Track Report register should be cleared. Applications could infer the track angle rate from the true airspeed and roll angle values.

5.3 Heading and Speed Report (Register 60_{16})

The Heading and Speed Report (register 60_{16}) contains five data fields, each incorporating its own status bit. The purpose of this register (like register 50_{16} described in section 5.2 above) is to aid conflict probe and long-term air traffic control functions in maintaining accurate aircraft horizontal track positions and velocities. The maximum acceptable data age for any of the fields in this register is 1 second – if this age is exceeded for any data field then its status bit is cleared. The update rate for each data field in the register should be sufficient to ensure that the maximum latency of each data value is not exceeded in normal operation. (Note: if all the five status fields in the register are simultaneously cleared, then the register itself is no longer valid. Its corresponding bit in the common usage capability register [17_{16}] should be cleared – which triggers a change in the data link capability register [10_{16}] and a broadcast message with the new contents of register 10_{16} via the air-initiated Comm B downlink protocol.) The following table lists the data fields in register 60_{16}.

1 Global Navigation Satellite System

Table 5-3: Data Fields in the Heading and Speed Report (Register 60_{16})

Data Value	LSB	Range	ARINC 429 word (octal)
Magnetic Heading	90/512 degrees	-180..180 degrees	320 (binary) 014 (BCD)
Indicated Airspeed	1 knot	0..1023 knots	206 (computed airspeed)
Mach	0.004 Mach	0..4.09 Mach	205
Barometric Altitude Rate	32 feet/minute	-6,384..16,352 feet/minute	212
Inertial Vertical Velocity	32 feet/minute	-6,384..16,352 feet/minute	365

5.4 Quasi-Static Parameter Monitoring (Register $5F_{16}$)

The Quasi-Static Parameter Monitoring register contains twelve 2-bit fields that indicate whether their respective flight parameter has changed its value. (Note: the remaining 32 bits in the register are reserved to monitor additional parameters.) A field value of 00 binary indicates that there is no valid data available for the particular monitored parameter. If valid data is available for the particular monitored parameter, then the field value cycles through binary values 01, 10, and 11 each time there is a change in the monitored parameter. A change in any of the fields in the quasi-static parameter monitoring register ($5F_{16}$) triggers a change in bit 23 of the common usage capability register (17_{16}) – which, in turn, triggers a change in the data link capability register (10_{16}) and a downlink broadcast message with the new contents of register 10_{16} via the air-initiated Comm B protocol. The following table lists the data fields in register $5F_{16}$ and the register that contains the parameter being monitored by that data field. Note that some of the monitored parameters (e.g., those indicating horizontal intent) do not currently have defined register locations. Some of this is due to changes in the register assignments over time. These fields are reserve for the future when their register assignments are finalized.

Table 5-4: Data Fields in the Quasi-Static Parameter Monitoring Register ($5F_{16}$)

Monitored Parameter	Register containing Parameter
MCP/FCU Selected Altitude	40_{16}
Selected Heading	--
Selected Speed	--
Selected Mach Number	--
Selected Altitude Rate	--
Selected Flight Path Angle	--
Next Waypoint	--
FMS Horizontal Mode	--
FMS Vertical Mode	40_{16}
VHF Channel Report	48_{16}
Meteorological Hazards	45_{16}
FMS Selected Altitude	40_{16}

6 1090 Extended Squitter (Mode S ADS-B)

This section discusses the registers and protocols used for Mode S Extended Squitter applications. A "squitter" is a spontaneous broadcast transmission by the Mode S transponder on the 1090 MHz frequency not initiated by an interrogation on 1030 MHz. Mode S support of "automatic dependent surveillance via broadcast" (ADS-B) is provided by means of squitters. Registers 05_{16} through $0A_{16}$ (plus 61_{16} to 65_{16}) are used by the extended squitter protocols. Note that registers 05_{16} through $0A_{16}$ have a matching capability bit in the common-usage capability register 17_{16} (see section 2.3 above). See [5] and [6] for the complete definition of the Mode S ADS-B application.

There are two defined standards for Mode S extended squitter applications. The initial standard [5] is termed "version 0". Using these message formats, ADS-B surveillance quality is reported in terms of the "Navigation Uncertainty Category" (NUC), which can be an indication of either the accuracy or the integrity of the navigation data used by ADS-B. However, there is no indication provided as to whether the NUC value is based on integrity or accuracy. The revised ADS-B standard [6] is termed "version 1". The version 1 formats overcome the limits of version 0 by reporting separately the "Navigation Accuracy Category" (NAC), the "Navigation Integrity Category" (NIC), and the "Surveillance Integrity Level" (SIL). The version 1 formats are fully compatible with the version 0 formats, in that a receiver built to either standard can correctly receive and process ADS-B messages generated by transmitting equipment built to either standard. Sections 6.1 through 6.6 of this paper cover version 0 formats, indicating where version 1 formats differ. Section 6.7 of this paper covers the version 1-specific format revisions.

There are 32 types of Mode S extended squitter messages denoted by a 5-bit format type code. Each squitter message begins with the 5-bit format type code. The following table describes the various format type codes, their related squitter formats, and the section in this paper that discusses the particular squitter type. (The "Navigational Uncertainty Category in Position" [NUC_P] is defined in [4] and [5]. It is a measure of the integrity and accuracy of the navigational data available from the aircraft's avionics, both horizontally and vertically.) Note that version 0 ADS-B uses NUC, while version 1 formats use NIC, NAC, and SIL. See section 6.7.1 of this paper for the format type coding used in version 1.

Table 6-1: Mode S Extended Squitter Format Type Codes (Version 0)

Format Type Code	Description	Altitude Type	Section Reference	NUC_P
0	No position information	Barometric or none	6.1	0
1	Identification (Category D)	N.A.	6.4	--
2	Identification (Category C)	N.A.	6.4	--
3	Identification (Category B)	N.A.	6.4	--
4	Identification (Category A)	N.A.	6.4	--
5	Surface Position	N.A.	6.2	9
6	Surface Position	N.A.	6.2	8
7	Surface Position	N.A.	6.2	7
8	Surface Position	N.A.	6.2	6
9	Airborne Position	Barometric	6.1	9
10	Airborne Position	Barometric	6.1	8
11	Airborne Position	Barometric	6.1	7
12	Airborne Position	Barometric	6.1	6
13	Airborne Position	Barometric	6.1	5
14	Airborne Position	Barometric	6.1	4
15	Airborne Position	Barometric	6.1	3
16	Airborne Position	Barometric	6.1	2
17	Airborne Position	Barometric	6.1	1
18	Airborne Position	Barometric	6.1	0
19	Airborne Velocity	Either	6.5	--
20	Airborne Position	GNSS	6.1	9
21	Airborne Position	GNSS	6.1	8
22	Airborne Position	GNSS	6.1	Reserved
23	Reserved for testing			
24	Reserved for surface system status			
25	Reserved			
26	Reserved			
27	Reserved			
28	Extended Squitter Aircraft Status		6.6.1	--
29	Was Current/Next Trajectory Change Point in version 0 [5] – no longer used in version 1 [6]		6.6.2	--
30	Aircraft Operational Coordination in version 0 [5] – no longer used in version 1 [6]		6.6.3	--
31	Aircraft Operational Status		6.6.4	--

The following table describes the NUC_P values for the case of barometric altitudes. The NUC_P categories are based on the "Horizontal Protection Limit" (HPL) and the "95% containment radius" (denoted "nu") for horizontal position error. The values of HPL and "nu" would be obtained from the avionics sources of aircraft position. If GNSS-derived altitudes are being used, an additional measure of the 95% containment radius for vertical position error would be factored into the determination of NUC_P. See [5] for a complete definition of NUC_P.

Table 6-2: Values of NUC_P for Mode S ES with Barometric Altitudes (Ver. 0)

NUC_P	HPL	nu
0	HPL ≥ 20 Nmi	nu ≥ 10 Nmi
1	10 Nmi ≤ HPL < 20 Nmi	5 Nmi ≤ nu < 10 Nmi
2	2 Nmi ≤ HPL < 10 Nmi	1 Nmi ≤ nu < 5 Nmi
3	1 Nmi ≤ HPL < 2 Nmi	0.5 Nmi ≤ nu < 1 Nmi
4	0.5 Nmi ≤ HL < 1 Nmi	0.25 Nmi ≤ nu < 0.5 Nmi
5	0.2 Nmi ≤ HPL < 0.5 Nmi	0.1 Nmi ≤ nu < 0.25 Nmi
6	0.1 Nmi ≤ HPL < 0.2 Nmi	0.05 Nmi ≤ nu < 0.1 Nmi
7	25 meters ≤ HPL < 0.1 Nmi	10 meters ≤ nu < 0.05 Nmi
8	7.5 meters ≤ HPL < 25 meters	3 meters ≤ nu < 10 meters
9	HPL < 7.5 meters	nu < 3 meters

6.1 Mode S Extended Squitter Airborne Position (Register 05_{16})

The Mode S extended squitter airborne position register is used to update the current aircraft position for Mode S ADS-B. Note that airborne velocity is provided via another register (see section 6.5 below). Also, note that the position and velocity for aircraft on the ground (as well as surface vehicles and fixed squitter installations) utilize another register (see section 6.2 below). The extended squitter airborne position register is broadcast (squittered) twice per second.

The format type code field value in the first 5 bits of the Mode S extended squitter airborne position register is used to denote the source of altitude information being used as well as the NUC_P value for version 0 (see section 6.0 above) for the source of horizontal positional data. Format type code values 9 through 18 denote NUC_P values ranging from 9 (most precise) to 0 (least precise) with barometric altitude data. Format type code values 20 through 22 denote GNSS-derived altitudes with NUC_P values 9, 8, and "reserved". (Since GNSS is providing the altitude data, it is assumed to be providing the horizontal position data as well.) The format type code field is based on the NIC value for version 1 (see section 6.7).

The next 2 bits in the airborne position register denote the Mode 3/A identity code emergency and other special conditions. The following table defines the coding for the "surveillance status" field. Note that the emergency condition (value=1) takes priority over the other cases.

Table 6-3: Mode S Extended Squitter Airborne Position Surveillance Status Field Coding

Value	Description
0	No emergency or other Mode 3/A code information
1	Permanent alert (emergency code)
2	Temporary alert (change of Mode 3/A code other than emergency)
3	“Special Position Indicator” (SPI)

Bit 8 in the airborne position register indicates whether the transponder has diversity transmitting antennas (1) or not (0). The next 12 bits in the airborne position register contain the altitude information, either barometric or GNSS-derived. Bit 21 of the airborne position register indicates whether the position information has been synchronized to the UTC time (1) or not (0). Time synchronization is only relevant for the top NUC_P levels (format type codes 9, 10, 20, and 21).

The position information in the airborne position register is compressed and encoded using the Mode S “Compact Position Reporting” (CPR) algorithm. (See [2], [4], [5], and [6] for a full definition of the CPR algorithm, as well as the assignment of ARINC 429 data words to the register data fields.) Bit 22 of the airborne position register holds the CPR format bit – CPR uses differing encodings for even and odd-second data in order to provide globally-unambiguous latitude and longitude values. The CPR-encoded latitude and longitude fields each occupy 17 bits.

When there is no horizontal (latitude/longitude) data available in the avionics (due to equipment failure or configuration) but altitude information is available, then the airborne position is sent with a format type code of zero and barometric altitude in its data field. If neither horizontal nor altitude data is available in the avionics, then the entire register (all 56 bits) should be cleared to zero – indicating the loss of information. This failure would be echoed by clearing bit 1 of register 17_{16} which would in turn cause bit 34 of register 10_{16} to be cleared. Further, downlink a of the new contents of register 10_{16} would be generated via the air-initiated Comm B broadcast protocol.

6.2 Mode S Extended Squitter Surface Position (Register 06_{16})

The Mode S extended squitter surface position register is used to update the aircraft (or surface vehicle/fixed device) position and velocity. Note that, unlike the airborne case, a single register is used for both position and velocity on the surface. (This is possible because there is no need to encode altitude in a surface position.) The surface position register is transmitted (squittered) twice per second if the aircraft/vehicle is in motion (> 10 meters in 30 seconds or ~0.65 knots). If the aircraft/vehicle is stationary, the squitter rate may be reduced to once every 5 seconds. (See section 6.3 where the extended squitter status register is described.)

The format type code field value in the first 5 bits of the surface position register is used to denote the “navigational uncertainty category for position” (NUC_P) value for the source of positional data in version 0 (see section 6.0). Format type code values 5 through 8 denote NUC_P values ranging from 9 to 6. NUC_P values less than 6 are not precise enough to provide surface position data. (See the table in section 6.0 above for a description of the NUC_P values.) The format type codes are based on NIC values for version 1 (see section 6.7).

The next 7 bits of the surface position register form the "movement" field. This data field encodes the aircraft or vehicle ground speed in a non-linear scaling. See [2] for the definition of this speed scaling. Bit 13 of the surface position register provides the validity status of the ground track field contained in bits 14 through 20 of this register. This 7-bit field encodes the true ground track angle (if valid) from 0 to 360 degrees in 128 steps.

The remainder of the surface position register encodes the surface position latitude and longitude using the CPR algorithm in the same way as the extended squitter airborne position (see section 6.1 above). Note that CPR uses a slightly different encoding for surface positions than it does for airborne positions – surface positions are more precise but have a more-limited range. (See [2], [4], [5], and [6] for a full definition of the CPR algorithm, as well as the assignment of ARINC 429 words to the register data fields.)

If surveillance data is not available in the avionics, then the entire register (all 56 bits) should be cleared to zero – indicating the loss of information. This failure would be echoed by clearing bit 2 of register 17_{16} which would in turn cause bit 34 of register 10_{16} to be cleared. Further, a downlink of the new contents of register 10_{16} would be generated via the air-initiated Comm B broadcast protocol.

6.3 Mode S Extended Squitter Status (Register 07_{16})

The extended squitter status register provides information about the current squitter rate selected by the avionics and also whether the source of altitude information currently being employed is barometric or GNSS-derived. Extracting this register allows an application to determine if the target transponder is squittering surface position at a lowered rate (to reduce the usage of the Mode S 1090 MHz channel for slow-moving vehicles). The first 2 bits of this register encode the surface squitter rate as defined in the following table. The lowered surface squitter rate may be selected when the aircraft (or vehicle) is moving less than 10 meters in 30 seconds (about 0.65 knots).

Table 6-4: Surface Squitter Rate Encodings for the Extended Squitter Status Register 07_{16}

Encoding	Description
0	No capability to determine surface squitter rate
1	High surface squitter rate selected
2	Low surface squitter rate selected
3	Reserved

The third bit of this register indicates use of barometric altitudes (if cleared to 0) or the use of GNSS-derived altitudes (if set to 1). All the remaining bits in the register are reserved for future use.

Note that this register was originally intended for use in avionics systems where the formatting of transponder contents is done in a device external to the Mode S transponder. This register serves as an interface between the transponder and the external register formatting function.

6.4 Extended Squitter Aircraft Identification and Category (Register 08_{16})

The Mode S transponder extended squitter aircraft identification and category register provides information about the type of vehicle and its identification. The contents of this register are broadcast every 5 seconds if the aircraft/vehicle is in motion (> 10 meters in 30 seconds or ~0.65 knots). If the aircraft/vehicle is stationary, the squitter rate may be reduced to once every 10 seconds. (See section 6.3 where the extended squitter status register is described.)

The aircraft identification information text string in this register is similar to that provided in the transponder aircraft identification register (register 20_{16}) described in section 4.1 above. See [4] for the assignment of ARINC 429 data words to the data fields in this register. The input text string could come from ARINC 429 data words 233-236_8 (Flight Identification), 301-303_8 (Aircraft Identification), or 360_8 (Flight Number).

As was described in section 6.0 above, there are four type code values (1..4) that are assigned to this register, depending on the category of the aircraft or vehicle carrying the squitter transmitter. Category A (type code 4) applies to standard types of aircraft. Category B (type code 3) applies to non-standard air vehicles. Category C (type code 2) applies to surface vehicles and fixed installations. Category D is currently unassigned. For each category, a 3-bit "category coding" value further defines the type of aircraft, vehicle, etc. The following table defines the values for the 3-bit vehicle category field in this register.

Table 6-5: Vehicle Category Coding Values in the Extended Squitter Register 08_{16}

Value	Category A Standard Aircraft	Category B Non-standard Aircraft	Category C Surface Vehicles
0	No data	No data	No data
1	Light (<15,000 lbs.)	Glider/sailplane	Emergency vehicle
2	Medium (<75,000 lbs.)	Lighter-than-air	Service vehicle
3	Heavy (<300,000 lbs.)	Parachute/skydiver	Fixed or tethered obstruction
4	High-vortex	Ultralight/Hang glider	Reserved
5	Very heavy (>300,000 lbs.)	Reserved	Reserved
6	High performance (>5g) and high speed (> 400 knots)	Unmanned air vehicle	Reserved
7	Rotorcraft	Spacecraft	Reserved

The remaining 48 bits of this register contain an 8-character text string that identifies the particular aircraft, vehicle, or other Mode S installation. The text string is encoded using a 6-bit character set (upper-case letters and decimal digits) in the same manner as the aircraft identification register (register 20_{16}) described in section 4.1 above.

6.5 Mode S Extended Squitter Airborne Velocity (Register 09_{16})

The Mode S extended squitter airborne velocity register provides the velocity counterpart to the airborne position register 05_{16} (see section 6.1 above). The extended squitter airborne velocity register is spontaneously broadcast (squittered) twice per second.

Beyond the format type code of 19 decimal in the first 5 bits, the airborne velocity register also incorporates a 3-bit "subtype" encoding to further subdivide the types of velocity encoding in use. The following table describes the subtype encoding values currently defined. Note that velocity can be expressed in two coordinate systems: Cartesian (east-west and north-south components of ground speed), and Polar (magnetic heading and airspeed). The Cartesian coordinate system is preferred – the polar encoding should only be used if the avionics cannot determine the ground speed components. Within each coordinate system, the speeds can be expressed in either the "normal" range (speed ≤ 1000 knots) or "supersonic" (speed > 1000 knots).

Table 6-6: Extended Squitter Airborne Velocity Register Subtype Encodings

Encoding	Velocity	Type
0	Reserved	
1	Cartesian (Ground Speed)	Normal
2		Supersonic
3	Polar (Airspeed, Heading)	Normal
4		Supersonic
5	Reserved	
6	Reserved	
7	Reserved	

Bit 9 of the airborne velocity register is set if a change in aircraft "intent" information has occurred. Aircraft intent is indicated by the contents of registers 40_{16} through 42_{16}. (Register 43_{16} is not included in the "intent" register set because it contains dynamic data and is always changing.) Having the intent flag in a squitter allows the receiving application to know when it should extract the aircraft intent registers. Note, too, that changes in register 40_{16} are indicated via a broadcast message. Bit 9 of the airborne velocity register is set 4 seconds after the update to one or more of the aircraft intent registers and is maintained for 18 seconds thereafter.

Bit 10 of the airborne velocity register is set if the squitter avionics are configured to support ADS-B based conflict detection or other higher-level ADS-B applications. Bits 11 through 13 of the extended squitter airborne velocity register contain the "navigational uncertainty category for rate" (NUC_R) encoding for velocity in version 0 (see section 6.0). Bits 11 through 13 contain the "navigational accuracy category for velocity" (NAC_V) in version 1 (see section 6.7). The following table contains the definitions for NUC_R.

Table 6-7: NUC_R Encodings in the Extended Squitter Airborne Velocity Register (Ver. 0)

NUC_R	Horizontal Velocity Error (95% containment)	Vertical Velocity Error (95% containment)
0	Unknown	Unknown
1	< 10 meters/second	< 50 feet/second
2	< 3 meters/second	< 15 feet/second
3	< 1 meters/second	< 5 feet/second
4	< 0.3 meters/second	< 1.5 feet/second

Bit 36 of the airborne velocity register is set if the vertical velocity value is derived from barometric altimetry. It is cleared if the vertical velocity value is derived from GNSS. Bit 37 is the vertical velocity sign bit (0=upward, 1=downward). Bits 38 through 46 of the airborne velocity register form the 9-bit vertical velocity field. Vertical velocity is expressed in units of feet per minute. The LSB for this field is 64 feet/minute. The value 0 in this field is reserved to indicate the lack of vertical velocity information – level flight is indicated by the value "1".

Bits 47 and 48 of the airborne velocity register are reserved for a future indication of aircraft maneuvering (left or right turn). Such an indicator would be used to improve the tracking of aircraft via ADS-B since true maneuvers could be immediately differentiated from data error.

The remainder of the airborne velocity register contains the difference between barometric altitude and GNSS-derived altitude (if both sources of data are available). Bit 49 of the extended squitter airborne velocity register indicates the sign of this difference (0=GNSS > Barometric, 1=GNSS < Barometric). Bits 50 through 56 of the extended squitter airborne velocity register contain the magnitude of the altitude difference in units of feet. The LSB for this field is 25 feet. As was the case for the vertical velocity field, the value 0 in this field is reserved to indicate the lack of data (either or both sources of altitude data unavailable). The value 1 in this field indicates no altitude difference.

6.5.1 Cartesian (Ground Speed) Encoding

If the subtype encoding in bits 6-8 of the Mode S extended squitter airborne velocity register is 1 or 2, then the velocity field encoding in bits 14 through 35 of the extended squitter airborne velocity register incorporates two 10-bit ground speed components (east/west and north/south), each with their respective sign bit (0=east or north). The field value 0 is reserved to indicate the lack of data – the encodings of ground speed begin with 1. The speed components are given in units of knots. If the subtype encoding is 1 (normal speed range), the LSB for this field is 1 knot. If the subtype encoding is 2 (supersonic speed range), the LSB for this field is 4 knots.

6.5.2 Polar (Heading and Airspeed) Encoding

If the subtype encoding in bits 6-8 of the airborne velocity register is 3 or 4, then the velocity field encoding in bits 14 through 35 of the airborne velocity register incorporates a magnetic heading component and an airspeed component. Bit 14 is a status bit for magnetic heading – it is set if magnetic heading data is available. The 10-bit magnetic heading value ranges from 0 to 360 degrees and is measured clockwise from magnetic north. Bit 25 indicates the type of airspeed data (0=indicated airspeed while 1=true airspeed). Bits 26 through 35 hold the airspeed field. The field value 0 is reserved to indicate the lack of data – the encodings of airspeed begin with 1. The airspeed is given in units of knots. If the subtype is 3 (normal speed range), the LSB for this field is 1 knot. If the subtype is 4 (supersonic speed range), the LSB for this field is 4 knots.

6.6 Mode S Extended Squitter Event-Driven Information (Register $0A_{16}$)

The Mode S extended squitter "event-driven protocol" provides a mechanism to generate Mode S squitters (spontaneous broadcasts of selected register contents) when particular events occur in the avionics rather than with a periodic schedule like the other squitters. Loading the extended squitter event-driven information register ($0A_{16}$) causes the Mode S transponder to generate a single squitter transmission containing the register contents. The Mode S transponder generates the event-driven squitter with minimal delay following the event that loaded register $0A_{16}$ (interleaving the event-driven squitter among the periodic squitters). If multiple "events" occur very close together in time, the squitters are queued in the transponder so that a maximum of two event-driven squitters per second are generated.

The avionics do not directly load register $0A_{16}$. The event-driven protocol is actually driven by loading one or more of the registers in the range 61_{16} through $6F_{16}$ (assuming that these registers are supported by the avionics). When a register in the range 61_{16}-$6F_{16}$ is loaded, the value is transferred into register $0A_{16}$ automatically. Loading register 61_{16} ("Emergency/Priority Status") takes precedence over the other "events" and would be squittered first – events involving registers 62_{16}-$6F_{16}$ employ a round-robin scheduling algorithm.

Currently, only the contents of registers 61_{16} through 65_{16} are defined. The following table lists the event-driven registers with their respective extended squitter format type code values. Note that registers 62_{16} and 63_{16} in the version 0 specification [5] share the format type code value 29 – these squitters were to be differentiated by the next bit in their contents. The version 1 specification [6] has removed these two register definitions from the ADS-B application because no support was generated for their operational use. They are now available for reassignment to other functions. See [3], [5], and [6] for a complete description of the contents of these registers. See [4] for the assignment of ARINC words to the data fields in these registers.

Table 6-8: Event-Driven Protocol GICB Registers and Type Codes

GICB	Type Code	Description
61_{16}	28	Emergency conditions in version 0. Shared with ACAS RA broadcast in version 1.
62_{16}	29	Current trajectory change point in version 0. Reserved in version 1.
63_{16}	29	Next trajectory change point in version 0. Reserved in version 1.
64_{16}	30	Aircraft operational coordination message
65_{16}	31	Aircraft operational status message

6.6.1 Emergency/ACAS RA (Register 61_{16})

Register 61_{16} (type code 28) is used to indicate emergency conditions on board the aircraft and to send this indication to the ground via the Mode S squitter event-driven protocol. This register is transmitted every 0.8 seconds. In version 1, this register is also used to indicate the generation of ACAS resolution advisories (RAs). A 3-bit "sub-type" value follows the type code. Sub-type=1 is used for emergency conditions, while sub-type=2 (in version 1) is used to indicate ACAS RA data. If the sub-type=1 (emergency), then a 3-bit data field indicates the type of emergency condition as defined in the following table (and the remaining 45 bits in the register are reserved). Note: termination of the emergency condition may be detected by reading the surveillance status field in the Mode S extended squitter airborne position data (register 05_{16}), described in section 6.1 above.

Table 6-9: Register 61_{16} Emergency Code Definitions

Emergency Code Value	Meaning
0	No emergency
1	General emergency
2	Lifeguard/Medical
3	Minimum fuel
4	No communications
5	Unlawful interference
6..7	Reserved

For version 1 equipment, sub-type=2 is used to indicate that register 61_{16} contains ACAS RA data as described for register 30_{16} in section 4.2 above. The only difference in the data format is that the first 8 bits of register 30_{16} contain the value 30_{16} while the first 8 bits of register 61_{16} contain type code=28 (in the first 5 bits) and the sub-type value 2 in the next 3 bits. Note: ACAS RA data (sub-type=2) takes priority over emergency data (sub-type=1) if both conditions occur simultaneously.

6.6.2 Current/Next Trajectory Change Point (Registers 62_{16}/63_{16})

Registers 62_{16} and 63_{16} share a common format (type code 29) for version 0 (they are simply reserved in version 1). They would be used to transmit the next two waypoints in the aircraft's flight plan via the Mode S squitter event-driven protocol (this could be useful in long-term conflict detection applications). The next bit after the type code is set to 0 for the currently active trajectory change point (TCP) and set to 1 for the next TCP. The next 4 bits define the type of TCP as defined in the following table.

Table 6-10: Register 62_{16}/63_{16} Trajectory Change Point (TCP) Type Encodings

TCP Type Encoding	Meaning
0	No TCP data
1	"Straight" (geodesic) course to a "fly by" waypoint
2	"Straight" (geodesic) course to a "fly over" waypoint
3	"Straight" (geodesic) course to a "speed change" waypoint
4	"Straight" (geodesic) course to a "vertical speed change" waypoint
5	Arc course to a "fly by" waypoint
6	Arc course to a "fly over" waypoint
7	Arc course to a "speed change" waypoint
8	Arc course to a "vertical speed change" waypoint
9	Holding pattern to a holding fix
10	Course from a waypoint, termination point unknown
11..15	Reserved

Bit 11 of the TCP registers is a status bit for the TCP data. The remaining bits in the TCP register may be expressed in either a 3-dimensional or 4-dimensional form. Bit 12 is set to 0 for a 4D TCP definition and bit 12 is set to 1 for a 3D TCP definition. A 4D TCP definition contains four data fields as defined in the following table.

Table 6-11: Register 62_{16}/63_{16} 4D TCP Encodings

Field Contents	Number of Bits	Value Range	Comments
TCP altitude	10	Up to 130,000 feet	LSB=128 feet
TCP latitude	14	"Compact Position Reporting" (CPR) 14-bit even-time format. TCP must be less than 160 nautical miles distant.	
TCP longitude	14		
Time to Go (TTG)	6	Up to 16 minutes (all 1's for TTG > 16 minutes)	LSB=0.25 minutes

A 3D TCP definition contains three data fields as defined in the following table. Note that the latitude and longitude encoding for 3D TCPs use straight 2's complement binary format rather than CPR encoding.

Table 6-12: Register 62_{16}/63_{16} 3D TCP Encodings

Field Contents	Number of Bits	Value Range	Comments
TCP altitude	10	Up to 130,000 feet	LSB=128 feet
TCP latitude	17	-180..180 degrees	LSB=$360/2^{17}$ degrees
TCP longitude	17	-180..180 degrees	LSB=$360/2^{17}$ degrees

6.6.3 Aircraft Operational Coordination Message (Register 64_{16})

The purpose of this register is to transfer parameters to support operational applications, particularly those involving paired aircraft (formation flying) via the Mode S squitter event-driven protocol. It is transmitted once every 5 seconds during the duration of the operation, except that the transmission rate is increased to once every 2 seconds for 30 seconds after a change in the register contents occurs. The first 5 bits of the register contain the type code of 30. The next 3 bits are reserved for a sub-type coding, but only sub-type=0 is currently defined. The next 24 bits of the register contain the address of the other aircraft in the paired operation. The next 5 bits define the runway threshold speed for the transmitting aircraft in increments of 5 knots. (The value 0 is reserved to indicate “no data” and the value 31 is reserved to indicate a speed greater than 245 knots.) The next bit indicates the sign of the aircraft’s roll angle, and the subsequent 5 bits encodes the roll angle in degrees. (Again, the value 0 is reserved to indicate “no data” and the value 31 is reserved to indicate an angle greater than 30 degrees.) The next 2 bits are used to indicate a “go around” condition (if the value is 2). The next 2 bits are used to indicate an “engine out condition” (if the value is 2). The remainder of the bits in the register are reserved.

6.6.4 Aircraft Operational Status Message (Register 65_{16})

The intent of the aircraft operational status message (register 65_{16}) is to provide the current capability class and operational mode of ATC-related applications on board the aircraft via the Mode S squitter event-driven protocol. The register 65_{16} data is to be transmitted every 1.7 seconds in version 0. The first 5 bits of the register contains the format type code value of 31. The next 3 bits form a sub-type field. Only the sub-type 0 is defined in version 0. Version 0 subdivides the next 32 bits into eight 4-bit fields covering such things as enroute operations/status, terminal operations/status, approach/landing operations/status, and surface operations/status. The remaining 32 bits are reserved. However, version 0 of register 65_{16} [5] only defines the first 4-bit field (enroute operations) as shown in the following table. “Enroute Operations” in version 0 is used to indicate the operational state of ACAS and “cockpit display of traffic information” (CDTI) avionics on board the aircraft. “ACAS operational” refers to a TCAS II unit operating in the TA/RA mode. All the other fields in the aircraft operational status message (register 65_{16}) were simply left “reserved”. Register 65_{16} gets a more complete definition in version 1 (see section 6.7.3 below).

Table 6-13: Version 0 Aircraft "Enroute Operations" Coding (Register 65_{16})

Value	ACAS	CDTI
0	Operational or unknown	Not operational or unknown
1	Operational or unknown	Operational
2	Not operational	Not operational or unknown
3	Not operational	Operational
4..15	Reserved	Reserved

6.7 Version 1 Mode S ADS-B Squitter Changes

As was discussed in section 6.0 above, the main difference between version 0 [5] and version 1 [6] of the Mode S ADS-B squitter format specification is that the version 0 formats employed a "navigation uncertainty category" (NUC) while the version 1 formats overcome the limits of version 0 by reporting separately the "navigation accuracy category" (NAC), the "navigation integrity category" (NIC), and the "surveillance integrity level" (SIL). Version 1 differences from version 0 fall into three areas:

(1) format type encoding uses NIC instead of NUC (see section 6.7.1);
(2) use of NAC instead of NUC for velocity (section 6.7.2); and
(3) a full definition of the aircraft operational status format message (section 6.7.3).

6.7.1 Version 1 ADS-B Format Type Encoding

The following table defines the ADS-B format type coding for version 1. It closely parallels the equivalent table for version 0 given in section 6.0 above, except for the substitution of NIC values for NUC values. Note that the NIC value expressed by the format type code is sometimes modified by the "NIC Supplement" bit in the aircraft operational status message (register 65_{16}) described further in section 6.7.3 below.

Table 6-14: Mode S Extended Squitter Format Type Codes (Version 1)

Format Type Code	Description	Altitude Type	Section Reference	NIC	NIC Supp.
0	No position information	Barometric or none	6.1	0	--
1	Identification (Category D)	N.A.	6.4	--	--
2	Identification (Category C)	N.A.	6.4	--	--
3	Identification (Category B)	N.A.	6.4	--	--
4	Identification (Category A)	N.A.	6.4	--	--
5	Surface Position	N.A.	6.2	11	0
6	Surface Position	N.A.	6.2	10	0
7	Surface Position	N.A.	6.2	9,8	1,0
8	Surface Position	N.A.	6.2	0	0
9	Airborne Position	Barometric	6.1	11	0
10	Airborne Position	Barometric	6.1	10	0
11	Airborne Position	Barometric	6.1	9,8	1,0
12	Airborne Position	Barometric	6.1	7	0
13	Airborne Position	Barometric	6.1	6	1,0
14	Airborne Position	Barometric	6.1	5	0
15	Airborne Position	Barometric	6.1	4	0
16	Airborne Position	Barometric	6.1	3,2	1,0
17	Airborne Position	Barometric	6.1	1	0
18	Airborne Position	Barometric	6.1	0	0
19	Airborne Velocity	Either	6.5	--	--
20	Airborne Position	GNSS	6.1	11	0
21	Airborne Position	GNSS	6.1	10	0
22	Airborne Position	GNSS	6.1	0	0
23	Reserved for testing				
24	Reserved for surface system status				
25	Reserved				
26	Reserved				
27	Reserved				
28	Extended Squitter Aircraft Status/ACAS RA		6.6.1	--	--
29	No longer used in version 1		6.6.2	--	--
30	No longer used in version 1		6.6.3	--	--
31	Aircraft Operational Status		6.7.3	--	--

Note: the following table describes the NIC values for barometric altitude cases. GNSS altitude cases may report only NIC=0, 10, or 11. The NIC categories are based on the 95% "radius of containment" for horizontal navigational error (R_C, also termed the "horizontal protection limit"

[HPL] or “horizontal integrity limit” [HIL]). The value of R_C, HPL, or HIL (ARINC Label 130_8) is obtained from the avionics sources of aircraft position. High values of NIC also require a “vertical protection limit” (VPL) measurement. See [6] for a complete definition of NIC.

Table 6-15: Values of NIC for Mode S Extended Squitter (Version 1)

NIC	R_C (HPL, HIL)	VPL
0	$R_C \geq 20$ Nmi.	--
1	$8 \leq R_C < 20$ Nmi.	--
2	$4 \leq R_C < 8$ Nmi.	--
3	$2 \leq R_C < 4$ Nmi.	--
4	$1 \leq R_C < 2$ Nmi.	--
5	$0.5 \leq R_C < 1$ Nmi.	--
6	$0.2 \leq R_C < 0.5$ Nmi.	--
7	$0.1 \leq R_C < 0.2$ Nmi.	--
8	75 meters $\leq R_C < 0.1$ Nmi.	--
9	$25 \leq R_C < 75$ meters	VPL < 112 meters
10	$7.5 \leq R_C < 25$ meters	VPL < 37.5 meters
11	$R_C < 7.5$ meters	VPL < 11 meters

6.7.2 Version 1 NAC Encoding for Velocity

The airborne velocity register 09_{16} described in section 6.5 above contains the value of the “navigational accuracy parameter for velocity” (NAC_V) in version 1 rather than the value of NUC_R as in version 0. The following table gives the definition for NAC_V when the avionics data source provides the 95% accuracy figure of merit for horizontal velocity ($HFOM_R$) and vertical velocity ($VFOM_R$). The tests indicated in the table are to be applied in the order shown, from most stringent to least stringent. The full definition of NAC_V is given in [6].

Table 6-16: Values of NAC_V For Airborne Velocity Register 09_{16} (Version 1)

NAC_V	$HFOM_R$ (meters/second)		$VFOM_R$ (feet/second)
4	$HFOM_R < 0.3$	AND	$VFOM_R < 1.5$
3	$HFOM_R < 1$	AND	$VFOM_R < 5$
2	$HFOM_R < 3$	AND	$VFOM_R < 15$
1	$HFOM_R < 10$	AND	$VFOM_R < 50$
0	$HFOM_R$ unknown or ≥ 10	OR	$VFOM_R$ unknown or ≥ 50

6.7.3 Version 1 Format for Aircraft Operational Status (Register 65_{16})

The aircraft operational status message (register 65_{16}) has been greatly extended in the version 1 format. (Section 6.6.4 above described the version 0 format of this message/register.) The following table illustrates the overall format of the version 1 aircraft operational status register. Note that some fields in this register are split between airborne and surface sub-type coding formats. The division of sub-fields within a data byte is not shown to scale.

Table 6-17: Version 1 Aircraft Operational Status Format (Register 65_{16})

<table>
<tr><th>Byte Number</th><th colspan="2">Data Field Description</th></tr>
<tr><td rowspan="2">1</td><td colspan="2">Format Type Code = 31</td></tr>
<tr><td>Subtype Code = 0 (airborne)</td><td>Subtype Code = 1 (surface)</td></tr>
<tr><td>2</td><td rowspan="2">Airborne Capability Class</td><td>Surface Capability Class</td></tr>
<tr><td>3</td><td>Length/Width Codes</td></tr>
<tr><td>4</td><td colspan="2" rowspan="2">Operational Mode Codes</td></tr>
<tr><td>5</td></tr>
<tr><td rowspan="3">6</td><td colspan="2">Version Number</td></tr>
<tr><td colspan="2">NIC Supplement bit</td></tr>
<tr><td colspan="2">NAC for Position</td></tr>
<tr><td rowspan="5">7</td><td>Barometric Altitude Quality (BAQ)</td><td>Reserved</td></tr>
<tr><td colspan="2">SIL Code</td></tr>
<tr><td>Barometric NIC</td><td>Track Angle/Heading</td></tr>
<tr><td colspan="2">Horizontal Reference Direction (HRD)</td></tr>
<tr><td colspan="2">Reserved</td></tr>
</table>

Like the version 0 format for register 65_{16} (section 6.6.4 above), the version 1 format starts with a 5-bit format type code value of 31. A 3-bit sub-type code follows the format type code. Version 1 defines two possible sub-types: airborne (sub-type=0), and surface (sub-type=1). The next 16 bits of the message format form a "capability class". The following table defines the airborne (sub-type=0) capability class format for version 1. Note that this format is backwards compatible with the version 0 definition of the aircraft operational status message.

Table 6-18: Version 1 Airborne Capability Class for Aircraft Operational Status (Reg. 65_{16})

Field Content	Number of bits	Encoding
Reserved (compatibility with Version 0)	2	00
Not ACAS	1	0=ACAS operational or unknown 1=ACAS not installed or not operational
Cockpit Display of Traffic Information (CDTI)	1	0=CDTI not operational 1=CDTI operational
Reserved	2	00
Air-referenced velocity (ARV) reporting capability	1	0=no ARV capability 1=ARV capability
Target State (TS) reporting	1	0=no TS capability 1=TS capability
Trajectory Change (TC) reporting	2	0=no TC capability 1=single TC capability 2=multiple TC capability
Reserved	6	Reserved

The surface capability class for the Version 1 format consists of 12 bits as defined in the following table.

Table 6-19: Version 1 Surface Capability Class for Aircraft Operational Status (Reg. 65_{16})

Field Content	Number of bits	Encoding
Reserved (compatibility with Version 0)	2	00
Position Offset Applied (POA)	1	0=POA applied 1=POA not applied
Cockpit Display of Traffic Information (CDTI)	1	0=CDTI not operational 1=CDTI operational
Reserved	2	00
Class B2 low-power transmitter	1	0= $\geq$ 70 watts 1= $<$ 70 watts
Reserved	5	Reserved

If the airborne operational status format is surface (sub-type=1), then a 4-bit length/width code field is appended to the capability class encoding (so that airborne and surface formats each use a total of 16 bits for the capability class portion of the overall register format). The aircraft length/width coding describes how much space the aircraft or ground vehicle occupies. Each aircraft or vehicle is assigned the smallest length/width code consistent with its actual dimensions. The smallest encoding from the following table is assigned for which the actual aircraft or vehicle's length and width are less than or equal to the bounding values from the table as given in units of meters .

Table 6-20: Version 1 Surface Length/Width Encoding for Aircraft Operational Status (Register 65_{16})

Length/Width Encoding	Upper Bound (Length)	Upper bound (Width)
0	15	11.5
1	15	23
2	25	28.5
3	25	34
4	35	33
5	35	38
6	45	39.5
7	45	45
8	55	45
9	55	52
10	65	59.5
11	65	67
12	75	72.5
13	75	80
14	85	80
15	85	90

A 16-bit operational mode field follows the capability code in the Version 1 format for both airborne and surface sub-types. The following table defines the operational mode encoding.

Table 6-21: Vers 1 Operational Mode Encoding for Aircraft Operational Status (Reg 65_{16})

Field Content	Number of bits	Encoding
Operational Mode Format	2	0=ACAS/IDENT/ATC 1..3=reserved
ACAS RA Active	1	0=ACAS II or ACAS RA not active 1=ACAS RA active
IDENT Switch Active	1	0=IDENT switch not active 1=IDENT switch active (for 18 seconds)
Receiving ATC services	1	0=not receiving ATC services 1=receiving ATC services
Reserved	11	Reserved

The next field in the Version 1 format is a 3-bit version number. A version number of zero indicates the support of Version 0 of the Mode S ADS-B squitter format [5]. A version number of one indicates support of Version 1 [6]. Version numbers 2 through 7 are reserved.

The next field in the Version 1 format is the NIC supplement bit as described in section 6.7.1 above. Following the NIC supplement bit is a 4-bit "navigational accuracy for position"

(NAC_P) encoding. This encoding is based on the 95% accuracy limit for horizontal position (HFOM) and, for the higher NAC_P values, the 95% "vertical estimated position uncertainty" (VEPU). The following table defines the NAC_P encoding. Note that if an update of NAC_P has not been received in more than 5 seconds, the NAC_P encoding of 0 (unknown) is to be used.

Table 6-22: Version 1 Aircraft Operational Status NAC_P Encoding for Aircraft Operational Status (Register 65_{16})

NAC_P	HFOM	VEPU	RNP
0	Unknown	Unknown	Unknown
1	4.0 ≤ HFOM < 10.0 Nmi.	--	10
2	2.0 ≤ HFOM < 4.0 Nmi.	--	4
3	1.0 ≤ HFOM < 2.0 Nmi.	--	2
4	0.5 ≤ HFOM < 1.0 Nmi.	--	1
5	0.3 ≤ HFOM < 0.5 Nmi.	--	0.5
6	0.1 ≤ HFOM < 0.3 Nmi.	--	0.3
7	0.05 ≤ HFOM < 0.1 Nmi.	--	0.1
8	45 ≤ HFOM < 92.6 meters	--	GPS with SA on
9	10 ≤ HFOM < 30 meters	15 ≤ VEPU < 45 meters	GPS with SA off
10	3 ≤ HFOM < 10 meters	4 ≤ VEPU < 15 meters	GPS with WAAS
11	HFOM < 3 meters	VEPU < 4 meters	GPS with LAAS
12..15	Reserved		

The next two bits in the Version 1 aircraft operational status message format are reserved for a barometric altitude quality (BAQ) indicator -- currently defaulted to 00. The next two bits after the BAQ define the "surveillance integrity level" (SIL) value as given in the following table. The SIL value relates to the containment radius R_C described for NIC encoding in section 6.7.1 above. Note that if an update of SIL has not been received in more than 5 seconds, the SIL encoding of 0 (unknown) is to be used.

Table 6-23: Version 1 Aircraft Operational Status SIL Encoding for Aircraft Operational Status (Register 65_{16})

SIL Code	Probability of Exceeding R_C without detection
0	Unknown
1	< 10^{-3} per flight hour or per operation
2	< 10^{-5} per flight hour or per operation
3	< 10^{-7} per flight hour or per operation

The next bit in the Version 1 aircraft operational status message format indicates the "barometric NIC" (NIC_{BARO}) for the airborne format (sub-type=0). This bit is reserved in the surface format (sub-type=1). A NIC_{BARO} value of 0 indicates that the barometric altitude is being reported using a Gilham coded input (subject to undetected bit errors) and has not been crosschecked against an alternative source of barometric altitude within the last 5 seconds. A

NIC_{BARO} value of 1 indicates that the barometric altitude is either based on a non-Gilham data source or has been crosschecked within the last 5 seconds. For the surface format (sub-type=1), this bit is used to indicate whether the heading/ground track angle field in the surface position message (register 06_{16} as described in section 6.2) contains target heading angle (bit=0) or track angle (bit=1).

The next bit in the Version 1 aircraft operational status message format indicates whether the reference direction for such parameters as heading, track angle, selected heading, selected track angle, etc. are referenced to true north (bit=0) or to magnetic north (bit=1). The remaining 2 bits in the Version 1 aircraft operational status message format are reserved.

7 Military Surveillance Applications

Registers $F1_{16}$ and $F2_{16}$ provide data in support of military surveillance applications. Through these two registers, Mode S applications can gain access to the aircraft's military Mode 1 and Mode 2 codes. Military register $F1_{16}$ is accessed through the normal GICB register extraction protocol, while register $F2_{16}$ is intended for DF=19 military squitter applications.

7.1 Military Register $F1_{16}$

Military register $F1_{16}$ contains two data fields, each with its own status bit. If the status bit indicates available data, the first data field contains the military Mode 1 code of the aircraft. The first bit of the field indicates the Mode 1 code format. If the format bit is 0, there are only 6 defined code bits expressed as two octal digits: A1,A2,A4 and B1,B2,B4. If the format bit is 1, there are twelve defined code bits expressed as four octal digits: A1,A2,A4, B1,B2,B4, C1,C2,C4, and D1,D2,D4. The actual bit ordering within the Mode 1 code data field is: C1,A1,C2,A2,C4,A4,X,B1,D1,B2,D2,B4,D4. The second data field in military register $F1_{16}$ contains the 12-bit Mode 2 code expressed as four octal digits in the same bit ordering as the Mode 1 bits. The remaining 27 bits in the register are reserved.

7.2 Military Register $F2_{16}$

Military register $F2_{16}$ is intended for DF=19 extended squitter applications (although it can be directly extracted as well). Such squitters contain a 3-bit "applications field" (AF) whose values are defined in the following table.

Table 7-1: DF=19 Applications Field (AF) Values

AF value	Application
0	Reserved for civilian extended squitter formats
1	Reserved for formation flight
2	Reserved for military applications
3..7	Reserved

The first 5 bits of military register $F2_{16}$ contain the "type code" that identifies the squitter format (similar to that described for civilian squitters in section 6 above). For this military squitter, AF=2 and the type code is one. Following the type code, the military register $F2_{16}$ contains three data fields, each with its own status bit. The first two data fields contain the military Mode 1 and Mode 2 codes, as described for military register $F1_{16}$ above. The third data field contains the 12-bit civilian Mode 3/A identity code expressed as 4 octal digits and in the same bit ordering as the 12-bit military Mode 1 and Mode 2 codes. By combining the civilian and military identity codes in a single register (and squitter), the receiving application can obtain all the identity information about the aircraft without having to perform direct Mode S interrogations for the Mode 3/A code.

References

[1] RTCA DO-181C, "Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment", June 12, 2001.

[2] ICAO International Standards and Recommended Practices, Aeronautical Telecommunications, Annex 10, Volume III, Communication Systems, Part I – Digital Communication Systems, July 1995.

[3] ICAO International Standards and Recommended Practices, Aeronautical Telecommunications, Annex 10, Volume IV, Surveillance Radar and Collision Avoidance Systems, July 1998.

[4] ICAO Manual on Mode S-Specific Services, Doc 9688, Second Edition, 2004 (with proposed updates).

[5] RTCA DO-260, "Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B)", 2000

[6] RTCA DO-260A, "Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B), 2003.

List of Acronyms

3D	Three Dimensional
4D	Four Dimensional
ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance via Broadcast
AF	Application Field
ARA	Active Resolution Advisories
ARINC	Aeronautical Radio, Incorporated
ARV	Air-Referenced Velocity
ATC	Air Traffic Control
ATN	Aeronautical Telecommunications Network
BAQ	Barometric Altitude Quality
BCD	Binary-Coded Decimal
CA	Mode S Transponder Capability
CDTI	Cockpit Display of Traffic Information
CPR	Compact Position Reporting
DF	downlink format
EHS	Enhanced Surveillance
ELM	Extended Length Message
ELS	Elementary Surveillance
ES	1090 MHz "Extended Squitter"
EUROCAE	European Organization for Civil Aviation Equipment
FCU	Flight Control Unit
FMS	Flight Management System
GAMA	General Aviation Manufacturers Association
GICB	Ground-Initiated Comm B
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HFOM	Horizontal Figure of Merit for Velocity
HIL	Horizontal Integrity Limit
HPL	Horizontal Protection Limit
HRD	Horizontal Reference Direction
ICAO	International Civil Aviation Organization
LAAS	Local Area Augmentation System

LSB	Least Significant Bit
MCP	Mode Control Panel
MHz	MegaHertz
MSP	Mode S-Specific Protocols
MTI	Multiple Threat Indicator
NAC	Navigation Accuracy Category
NIC	Navigational Integrity Category
NUC	Navigation Uncertainty Category
POA	Position Offset Applied
RA	Resolution Advisory
RAC	RAs Active
RAT	RA Terminated
RTCA	Radio Technical Commission for Aeronautics
SA	Selected Availability
SI	Surveillance Identifier
SIL	Surveillance Integrity Level
SPI	Special Position Indicator
TA	Traffic Alert
TC	Trajectory Change
TCAS	Traffic Alert and Collision Avoidance System
TCP	Trajectory Change Point
TID	Threat Identity Data
TIS	Traffic Information Service
TS	Target State
TTG	Time To Go
TTI	Threat Type Indicator
USAF	United States Air Force
UTC	universal time code
VEPU	Vertical Estimated Position Uncertainty
VFOM	Vertical Figure of Merit for Velocity
VNAV	vertical navigation
VPL	Vertical Protection Limit
WAAS	Wide Area Augmentation System